

DEVICE FOR PROTECTION AGAINST ELECTROSTATIC DISCHARGES
FOR MICROELECTRONIC COMPONENTS ON SOI TYPE SUBSTRATE

Technical field

This invention relates to a device for protection against electrostatic discharges for electronic components made on a substrate comprising a semiconducting layer on an insulating layer, for example an SOI substrate.

Protection against electrostatic discharges (ESD) has an important influence on the reliability of electronic systems. According to some sources, losses caused by electrostatic discharges account for an average loss of products varying between 8 and 33%. Protection against these nuisances is necessary at all levels; manufacturing and operating environment of integrated circuits, protection on cards combining several integrated circuits. Part of the protection is provided by the circuit itself.

The various integrated circuits used in electronic systems are connected to their environment through their input-output or power supply pins, and therefore if an electrostatic discharge (ESD) occurs, it can be passed through these pins. The main principle for protection on the circuit is then to put protection structures between these pins and their power supplies at each input-output pin around the periphery of the circuit. These protective structures are usually inverse diodes, blocked MOS transistors or thyristors. These devices must not disturb operation of the circuit and must behave like open switches during normal

operation in order to directly divert the minimum amount of input-output current that forms the vector for carrying information in the circuit, to the circuit power supplies. On the other hand when a discharge 5 occurs, they must behave like closed switches to prevent the electrostatic discharge from degrading the internal part of the circuit. If a discharge occurs, and if the protection really operates like an ideal switch, in other words a zero resistance series switch, 10 the electrostatic discharge will flow through the circuit without any loss of energy and therefore without deterioration. The electrostatic discharge voltage resisted by the protection device without being damaged is called the intrinsic withstand.

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State of prior art

The switch analogy is an ideal case, and an attempt will be made to approach this ideal case. In practice, protection is characterized by its electrical 20 characteristic hold voltage in triggered mode and its resistance in series. Therefore, optimising protection means minimizing the size of the structure, with a minimum resistance in series and for which the hold voltage is minimized, although remaining greater than 25 the circuit operating voltage. The reduction in the surface area occupied by the protection structure and the reduction in its resistance are usually contradictory, and a compromise has to be reached between these two factors.

30 At the present time, integrated circuits operating at increasing low voltages (less than 3 V and even less

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than 2 V) can now be made. The maximum allowable voltages are also lower and optimisation of the series resistance of protection structures, and achieving an optimum hold voltage become essential challenges.

5 Protection structures using several directly polarized diodes have been used within this context of protection of low voltage circuits. The hold voltage is defined as a first approximation by the diode elbow voltage (about 0.7 V) multiplied by the number of
10 diodes in series.

The use of this type of protection by diodes in series creates difficulties on a classical silicon substrate due to the fact of a parasite effect commonly called the Darlington effect. On this type of
15 substrate, each protection diode is made in a compartment with doping type opposite to the doping type of the substrate, each compartment being isolated from the others, the diodes then being connected in series. Since the substrate is solid, a parasite bipolar
20 transistor is connected to each protection diode. The protection diode leakage current corresponds to the basic current of the transistor connected to the next protection diode and the leakage current is correspondingly amplified. Document WO 97/35373
25 proposes a solution to this problem by decorrelating the isolation and protection functions. The Darlington effect is used to perform the electrostatic discharge evacuation function. The size of the first diode is maximized since the first diode receives the largest
30 part of the discharge. The isolation function is then

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performed by a MOS transistor connected in series with the last protection diode.

The Darlington effect does not occur in microelectronic circuits made on SOI (silicon on insulator) substrates since parasite bipolar transistors are eliminated. Protection by diodes in series can therefore be applied on these substrates.

The article entitled "Dynamic Threshold Body-and Gate-Coupled SOI ESD Protection Networks" by S. VOLDMAN et al. published in EOS/ESD Symposium proceedings, 1997, Santa Clara, California, pages 210-220, divulges a protection device using diodes made on an SOI substrate. The protection diodes are then made from MOS transistors. For such a transistor made on SOI substrate, the area under the grid causes a problem due to the fact that the buried insulating layer prevents dissipation of heat, which is contrary to what happens for a solid silicon substrate. This article emphasizes protections in which the diode is made between firstly the drain, substrate and grid, and secondly the source. However, the most compact useable diode consists of an NMOS transistor with a different type of source implant and drain implant. Some manufacturing techniques require a small thickness of silicon on the buried oxide layer, and the formed diodes then have a high resistance. The area under the grid of a protection diode can melt when an electrostatic discharge occurs, since the heat produced cannot easily be dissipated.

Presentation of the invention

The invention provides a solution to the problem of protecting microelectronic circuits produced on SOI type substrates. It is applicable to the very 5 particular context of low consumption integrated circuits. The general principle of the invention is to use a device which also has very bad inverse withstand performances and cannot be used in a circuit without modification due to the leaks that it causes. This 10 device is a Zener type diode. This term refers to a diode with a low avalanche voltage. Its bad inverse withstand is not a disadvantage in the case of the invention, since the diode will always be directly polarized.

15 The Zener diode used according to this invention is a diode formed by the junction between two opposite and highly doped zones. The direct characteristics and the inverse characteristics are correspondingly degraded and the result is that the diode cannot be 20 used in an application for which this type of diode is usually used. Its conduction level at a given voltage is then increased, while its blocking aspect when inversely polarized disappears. Leaks with low polarization voltage are also higher than with a 25 classical diode.

The advantage of Zener diodes is that their intrinsic voltage withstand at an electrostatic discharge is high. This is particularly true in the case of a thin substrate (see FIGURE 7). Furthermore 30 they have a lower series resistance and their gain is

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increased by a factor of 3. These two parameters are essential to optimise protection.

Therefore, the purpose of the invention is a device for protection of an electronic component
5 against electrostatic discharges, the device being made in a semiconducting layer of a substrate, the semiconducting layer covering an insulating layer, the device being connected to a contact pin to protect the said component in order to divert an electrostatic
10 discharge, characterized in that the device comprises at least one Zener diode connected to the said pin to be directly polarized.

In general, this device comprises several Zener diodes mounted in series and connected to the said pin
15 to be directly polarized. The Zener diodes may be laid out adjacent to each other to form the circuit in series, the electric link between two adjacent diodes being obtained by metallisation or by a silicide.

Advantageously, each Zener diode comprises two
20 regions highly doped with opposite types of conductivity, these two regions being separated by a medium doping region according to one or the other of the said types of conductivity. Preferably, if the semiconducting substrate layer is a silicon layer, the
25 doping levels in the two strongly doped regions is of the order of 10^{20} atoms/cm³, and the doping level in the region doped at an average level is of the order of 10^{18} atoms/cm³. This substrate may be an SOI substrate.

30 In order to overcome the problem of dissipation of heat from a protection diode made on a semiconducting

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surface layer supported on an insulating layer that is a poor dissipator of heat (for example an SOI substrate), it is proposed to make this diode without starting from a transistor to avoid the presence of a 5 grid, in order to obtain the greatest volume and thus enable dispersion of heat. The silicon will be thinned if necessary at the grid.

Another purpose of the invention is a process for embodiment of a device for protection of an electronic 10 component against electrostatic discharges, the protection device comprising at least one Zener diode made in a semiconducting layer of a substrate, the semiconducting layer covering an insulating layer, the process comprising:

- 15 - a step to define the zone of the diode or the active zone, in the said semiconducting layer,
- a step to implant a first zone in the said active zone, to obtain a first zone with medium doping according to a conductivity type chosen between a first 20 conductivity type and a second conductivity type opposite to the first conductivity type,
- a step to implant a part of the said first zone, to obtain a second strongly doped zone according to the said first conductivity type, the second zone being separated from the unimplanted part of the active zone by the remaining part of the first zone,
- a step to implant the unimplanted part of the active zone to obtain a third zone with strong doping according to the said second conductivity type.

30 Another purpose of the invention is a process for making a device for the protection of an electronic

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component against electrostatic discharges, the protection device comprising at least one Zener diode made in a semiconducting layer of a substrate, the semiconducting layer covering an insulating layer, the 5 process comprising:

- a step to define the zone of the diode or the active zone in the said semiconducting layer,
- a step to implant a first zone near the central part of the active zone, to obtain a first medium doped 10 zone according to a conductivity type chosen between a first conductivity type and a second conductivity type opposite to the first conductivity type,
- a step to form a grid made of a conducting material on the first zone, after formation of a thin 15 grid oxide layer,
- a step to implant a second zone of the active zone adjacent to the first zone, to obtain a second zone with strong doping according to the first conductivity type,
- 20 - a step to implant a third zone in the active zone, adjacent to the first zone that separates it from the second zone, to obtain a third zone with strong doping according to the second conductivity type. Preferably, the first zone is wider than the grid 25 formed on this first zone.

Brief description of the drawings

The invention will be better understood and other advantages and specific features will appear after 30 reading the following description, given as a non-

limitative example accompanied by the attached drawings, among which:

- FIGURE 1 diagrammatically shows the composition of a Zener diode that can be used in the protection device according to the invention;
- FIGURE 2 is a descriptive view of the implant of a Zener diode on a very thin substrate layer that can be used in the protection device according to the invention;
- 10 - FIGURE 3 is a descriptive view of the implant of a Zener diode on a thin layer of a substrate that can be used in the protection device according to the invention;
- FIGURE 4 represents an electronic circuit protected by protection devices according to the invention;
- 15 - FIGURE 5 represents the implant of a set of four Zener diodes mounted in series on a very thin layer of a substrate, for a protection device according to the invention;
- 20 - FIGURE 6 represents the implant of a set of four Zener diodes mounted in series on a thin layer of a substrate, for a protection device according to the invention;
- FIGURE 7 is a cross sectional view of MOS transistor according to known art;
- FIGURES 8 to 11 are cross sectional views of an SOI substrate during various manufacturing steps of a Zener diode for a protection device according to the invention.

Detailed description of embodiments of the invention

FIGURE 1 diagrammatically shows the composition of a Zener diode that can be used in the protection device according to the invention. This Zener diode is made 5 from single crystalline silicon using two strong source and drain type implants that can be used to achieve doping of the order of 10^{20} atoms/cm³. These two opposite types of implants, N⁺⁺ for region 1 and P⁺⁺ for region 2, are separated by an intermediate N or P type 10 implant in region 3 of the order of 10^{18} atoms/cm³. This diode is specific in its design and its low resistance. This Zener diode may be made differently depending on 15 the techniques used.

When a classical diode is made starting from a MOS 20 transistor configuration on a very thin layer of an SOI type substrate, the low intrinsic withstand of the protection diode is explained partly by the lower thickness of silicon due to local thinning. Furthermore, zones with the lowest doping located under 25 spacers can induce a high series resistance of the diode, particularly for implants corresponding to the PMOS transistor.

It is proposed that each Zener diode in the protection device according to the invention should be 30 made as follows, in order to overcome these disadvantages. The polysilicon grid masking level is not used. The implant level used for spacers in the NMOS transistor (slightly doped N or LDDN drain) is dissociated from the N drain and source (DSN) level. The P source drain (DSP) level that is normally the

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complement of the DSN level, becomes the complement of the DSN and LDDN levels.

FIGURE 2 shows a descriptive view of the implant of a Zener diode on a very thin layer of a substrate.

5 In order to make this diode, an active silicon zone 5 is defined in the silicon surface layer of an SOI substrate. An LDDN type implant level 6, and an N⁺⁺ type implant layer 7 are made. The DSP level is complementary to the DSN and the LDDN levels.

10 The following table presents the electrical results in terms of ESD withstand and electrical resistance, for a diode according to known art and a Zener diode made using similar techniques and with the same characteristics.

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	ESD withstand (volts/ μ m)	R (Ω)
Diode	7 V/ μ m	1400 Ω μ m
Zener diode	11 V/ μ m	470 Ω μ m

The intrinsic withstand expressed in volts per micrometer, is a value used in the standard test for protection against electrostatic discharges called HBM 20 (for "Human Body Model"). This test was defined by considering that a person can be represented by a capacitor with a capacitance of 100 pF, the skin resistance varying between 500 and 50 000 Ω . This standard refers to a device mounted in series with 25 a 100 pF capacitor, a 1500 Ω resistance and implicitly a 7.5 μ H inductance. It is said that a device has a

withstand of 2000 V (HBM) if it is not damaged by the discharge of a capacitor charged to 2000 V, this discharge taking place through the 1500Ω resistance and the $7.5 \mu\text{H}$ inductance. The voltage withstand is 5 then normalized per unit width of the protection device.

With this type of tester, and due to the high value of its series resistance which is 1500Ω , a voltage transient of U volts actually corresponds to a 10 current transient with a maximum current of about $U/1500$ amperes, a rise time of 5 to 10 nS and an exponential decay with a time constant of 150 nS. This current transient causes a certain temperature rise due to the Joule effect. The ESD withstand in terms of 15 volts per μm corresponds to a limit beyond which the energy dissipated in the device causes a destructive temperature runaway. The temperature runaway threshold may be related to a critical temperature that must not be exceeded. The temperature rise in the material 20 during the ESD transient corresponds to dissipation of heat by the Joule effect together with the high current transient. At the same current densities, the temperature rise for the SOI substrate is greater than for a solid substrate, since heat cannot be dissipated 25 as easily through the back of the substrate due to the presence of the buried oxide layer. The increase in the intrinsic withstand implies an increase in the thickness of the surface silicon layer.

In the above table, the gain in terms of intrinsic 30 withstand and electrical resistance of the diode

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according to the invention, is obvious compared with the classical diode.

For another type of technique, namely thin silicon surface layers, local thinning is not used to make a 5 classical diode produced from a classical MOS transistor. In order to overcome resistance problems under the spacer, at least one specific N type implant is used for the purposes of this invention, together with doping of the same order of magnitude as that used 10 for the intermediate zone of the Zener diode, over the entire active zone. This implant creates doping of a few 10^{18} atoms/cm³ and is done instead of the threshold adjustment implant done for a classical diode.

The implant then used to make the Zener diode 15 according to the invention is shown in FIGURE 3. In order to produce this diode, an active silicon zone 10 is defined in the silicon surface layer of an SOI substrate. An N⁺⁺ type implant level 11, a P⁺⁺ type implant level 12, an N type implant level 13 and a 20 polysilicon grid 14 are made.

The protection device using Zener diodes according to the invention cannot be used in the same way as protection devices with classical diodes. Zener diodes in the protection device according to the invention are 25 polarized directly.

For example, FIGURE 4 shows an electronic circuit protected from electrostatic discharges by four protection devices according to the invention. The ground pin 21, the DC power supply pin 22, the circuit 30 input pin 23 and the circuit output pin 24 are connected to protection devices 25. These protection

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devices 25 are formed from four Zener diodes mounted in series and polarized directly. The number of diodes in a device must be sufficient, in order to resist the power supply voltage without inducing an excessive 5 leakage.

The protection device according to the invention may advantageously be completed by the addition of classical inverse polarized diodes at several locations in the circuit in order to increase the efficiency of 10 the protection regardless of the sign of the electrostatic discharge. Thus, references 26 and 27 denote classical diodes installed in addition to some protection devices according to the invention.

Diodes in the protection device shall be mounted 15 in series, consequently it is judicious to design the device to enable the most compact possible integration. This is done by making the four diodes on the same active zone. If the diodes are made using an LDDN level differentiated from the DSN level (see FIGURE 2), these 20 diodes can be connected to each other through the metallisation level. This is illustrated in FIGURE 5. The four diodes 31, 32, 33 and 34 are shown with their different implants, for example for the Zener diode 33, the DSP implant 331, the DSN implant 332 and the LDDN 25 implant 333. Metallisations 35 connect the diodes to each other and to the outside. References 36 represent electrical contact points between diodes and metallisation.

If the diodes were made using an LDDN type level 30 used in front of the grid, then the diodes can be connected by a silicide level as illustrated in

FIGURE 6. The result is an even more highly integrated device. The four diodes are referenced 41, 42, 43 and 44. Each diode, for example diode 43, comprises a DSP implant 431, a DSN implant 432 and a polysilicon 5 grid 433. References 46 represent electrical contact points at the input and output of the protection device with four Zener diodes.

A classical diode is usually made by producing a MOS transistor. FIGURE 7 shows a cross section of such 10 a transistor made on an SOI substrate formed from a solid part 50 made of silicon, a layer of silicon oxide 51 and surface layer of silicon 52. The local thinning area created in the surface layer 52 can be noted. This local thinning area supports the grid oxide 15 layer 53, the polysilicon grid 54 and the spacers 55. Classical diodes are made using this concept and it is obvious that the volume of silicon between the grid oxide 53 and the oxide layer 51 is too confined. The heat produced in this volume cannot easily be 20 dissipated, unlike elements made on the solid silicon substrate.

According to the invention, Zener diodes can be made avoiding local thinning related to the polysilicon grid. The diode is made with a single LDD level as 25 shown in FIGURE 2. This is an innovative modification of a standard process since a device is used which also has very bad inverse withstand performances and which cannot be used as such in a circuit due to the leaks that it causes.

30 FIGURES 8 to 11 illustrate the production of a Zener diode for a protection device according to the

invention, starting from an SOI substrate. FIGURE 8 shows a cross-section of an SOI substrate composed of a solid part 60 made of silicon, a silicon oxide layer 61 and a silicon surface layer 62. As shown in FIGURE 9, 5 an LDDN type implant is made on part of the surface layer 62 to obtain an N^+ doped zone 63. As shown in FIGURE 10, an N drain-source (DSN) type implant is then made on part of the zone 63 that already has an N^+ type doping. This gives a zone 64 with N^{++} doping. A P drain- 10 source type (DSP) implant is then made in zone 65 in order to complete the Zener diode, as shown in FIGURE 11.

In general, the doping in the different zones forming a Zener diode in the device according to the 15 invention will be greater than or equal to 10^{13} atoms/cm³.

This Zener diode design is inexpensive, since, although it obviously needs an additional reticle, the LDDN level is dissociated from the DSN level and the 20 resulting production process is not more complex. The protection function is optimised; the intrinsic withstand is increased and the voltage drop developed at the terminals of the protection diode during an electrostatic discharge is minimized. This is shown in 25 the table shown above: 60% gain on the intrinsic withstand and 200% gain on the electrical resistance, which is actually the most critical parameter.

The invention succeeded in reaching a compromise. As doping on the LDD side increases, the avalanche 30 voltage reduces and the direct trip voltage also

reduces. The result is better evacuation of the electrostatic discharge wave.

The isolation capacity reduces as the doping increases. This type of diode made with these non-
5 classical characteristics result in structures that produce high leakage currents but when put in series the isolation capacity is compensated and these diodes are very efficient in evacuating charges.

The invention has the following advantage: when
10 the power supply voltage decreases down to 1 V, the result obtained using two degraded diodes mounted in series provides an excellent protection with low resistance. The inventor of this invention has proved an initial assumption by using a very bad quality of
15 this component.